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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

DEWATERING AND SELF DEWATERING OF CONCENTRATES
Parts A and B

M.J. Stefanski
Mineral Processing Laboratory

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Iron Ore Processing

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DEWATERING AND SELF DEWATERING OF CONCENTRATES

PROGRESS REPORT

by

M.J. Stefanski

Project: 30.13.02:	Iron Ore Processing
Project leader:	Wayne Cameron
Project element:	Self dewatering concentrates
Research carried out by:	M. Stefanski
Starting date:	August 15, 1986

Project Element Objective

To investigate and attempt to determine the reasons for the self dewatering characteristics of the iron ore concentrate from Quebec Cartier Mine. These self dewatering characteristics result in losses of considerable tonnage/annum for which the company is penalized.

Part A: GENERAL

SUMMARY

The phenomenon of self draining of iron ore concentrate has been described and the resulting industrial problems at Mont Wright, Québec Cartier Mines identified. A literature review including about 80 items in eight related fields was completed and discussion on the present state of knowledge and theory carried out. Materials to be tested were analysed and/or characterized. It was assumed and to a large extent proven that dewatering by centrifuging can serve as a physical model of moisture drainage during transport and storage of concentrates.

Kinetics of water drainage by centrifuging was studied and the use of water sequestering agents like bentonite and peat moss investigated. An addition of 1.7 to 2% of peat moss prevents self drainage of concentrate. By adequate conditioning of peat moss this amount can probably be substantially reduced.

The influence of two surfactants on self draining was studied.

A short term program for further experimental work as well as a long run investigation program of dewatering/self draining have been established.

Keywords: self draining of iron ore concentrates, dewatering of iron ore concentrates, moisture migration, handling of iron ore concentrates, water sequestering in iron ore concentrates.

Part A: GENERAL

RESUMÉ

Le phénomène de la migration d'eau dans le concentré de minerais de fer a été décrit et les problémes industriels qui en resultent à Mont Wright, Québec Cartier Mines, ont été identifiés. Une revue de la litérature contenant 80 titres classés dans huit differents domaines - a été complétée. Les titres pertinents sont accompagnés de commentaires et brefs resumés. Une discussion sur l'état présent de la science et de la théorie relatives au sujet de la migration d'eau/deshydratation a été présentée. Les matériaux devant servir aux expériences ont été analysés et/ou caractérisés. On a prouvé - jusqu à un certain degré - que l'essorage par centrifugation peut servir de modèle physique de la migration qui apparait lors du transport et du stockage des concentrés.

La cinétique d'essorage par centrifugation a été étudiée ainsi que l'utilisation de réactifs séquestrant l'eau - comme la bentonite ou la tourbe. En ajoutant 1.7 à 2 pour cent de tourbe on peut arrêter la migration d'eau dans le concentré. En conditionnant la tourbe avant l'utilisation on peut probablement réduire cette quantité considérablement.

On a etudié l'effet de deux agents chimiques sur la migration d'eau. Un programme de travaux expérimentaux à court terme sur la déshydratation/migration d'eau ainsi qu'un programme de recherche a long terme sur le même sujct ont été établis.

CONCLUSIONS

Notice: For reasons given in the "Introduction" these conclusions should be considered only as preliminary. They need to be confirmed by more tests so that results can be statistically proven.

1. The problem of self-dewatering (moisture migration) of the iron ore concentrate during transport and storage can be resolved in two ways:

   a) by more complete water removal during processing, for example by using adequate filter aids;
   b) by preventing subsequent moisture drainage using water sequestering agents.

2. Dewatering an iron ore concentrate using a centrifuge can be regarded as a physical model of moisture drainage during transport and storage.

3. Adding about 1.7 to 2% of peat moss or 0.5% of Wyoming bentonite prevents self dewatering of filtered concentrate. Adequate conditioning of peat moss would probably significantly reduce the indicated amount.

4. Surfactants influence greatly the water retention characteristics of the iron ore concentrate. Their use can help to reduce the moisture of filter cake and/or reduce the effect of self dewatering during handling.

5. There is potential for resolving problems connected with the self dewatering of Mont Wright concentrate. To achieve this the program of further research laid out in parts B and C of this report should be continued.

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DISCUSSION OF THE PRESENT STATE OF THEORY AND KNOWLEDGE

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* Notice: This part is edited as a separate volume

INTRODUCTION

Physical and physico chemical phenomena of moisturing and dewatering of dispersed or porous media - to which group fine grain bulk materials belong - as well as the flow of fluids through these media are studied in connection with the following branches of technology and science:

1. Dewatering of fine bulk materials by mechanical methods: thickening, filtering, centrifuging, draining; mineral processing in general;
2. Civil engineering and soil mechanics for construction purposes;
3. Exploitation of oil, natural gas and sulphur;
4. Underground and open-cast mining;
5. Applied geology;
6. Chemical engineering;
7. Agrophysics;
8. Transport of fine bulk materials;
9. Many other technologies less connected with mineral sciences.

Amazingly - as H. Schubert [1,2]* stated - up to the recent time, for many investigated problems there was little exchange of experience and knowledge between these particular fields. Therefore in order to get a fairly comprehensive overview of the knowledge connected with the phenomenon of self drainage/dewatering of fine bulk materials, technical literature in several technical and scientific areas has to be studied.

The Review of Literature (see the third part of this report) has been divided, for easier orientation, into 8 fields.

The second experimental part of this study was meant to be the most simple and the most practical possible so that all findings could be immediately and directly applied to the industrial practice. Experiments carried out do not necessarily have to serve cognitive purposes but their results should be directly transferable to the industry.

The third part of this study will contain a literature overview, a somewhat deeper discussion of the state of knowledge and theory and, if possible, will be oriented more toward the explanation of related phenomena.

(The intention of the author is to keep this partition during the next year of work on this problem.)

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* Numbers in square brackets refer to the overview of literature, part C of this report.

It has to be noted that work described in this progress report has been done with very modest means because the manpower involved did not exceed 0.2 person/year. All results of experiments should be treated with suspicion and as very preliminary only. For any serious practical and scientific purpose all experiments have to be systematically repeated so that results can be statistically proven.

IDENTIFICATION OF THE PROBLEM

Self drainage of Mont Wright concentrate during its transportation and storage has been recognized by Quebec Cartier Mines as a high priority problem, the solution of which could prevent significant losses incurred by the industry.

The concentrate is being dewatered on pan filters equipped with hoods for steam supply. Without steam the final moisture content in the concentrate was 4.5 to 5%. Passing steam at a temperature of ≈150°C through the cake reduces the moisture by 0.5%. On average a concentrate having 4.25% moisture is being loaded into railway cars.

The steam not only decreases moisture but also heats the concentrate up so that it does not freeze on its way to Port Cartier during the winter. The use of steam costs the mine $2 to 2.5 million a year. In summer time a big part of this money could be saved if it did not serve to reduce moisture.

To further reduce the final moisture of the concentrate the surfactant Alchem 8103 was used as a filter aid. At an additional rate of 3.5 g/tonne concentrate [2.7], it reduced the moisture significantly but the dewatered concentrate became sticky and difficulties in handling it were observed. Therefore its use was abandoned.

After being loaded into railway cars and during its trip to Port Cartier, the concentrate loses about 0.5 to 1% of its moisture by self-draining. Shaking and vibration of the railway car probably enhance the process of drainage.

When the material is stored in bins at the Port Cartier loading point further migration of moisture occurs so that the material becomes much wetter at the bottom of the bin than in the upper part. Therefore, about 10% of the bin content, is directed to open storage for further drainage, while the remaining 90% is loaded onto ships.

Such separate treatment of a part of the concentrates involves additional costs and disturbs the normal handling procedure.

During transport in ships holds, although it had originally only 3 to 3.5% moisture, the concentrate undergoes further self draining. Tests carried out in 1962 on Carol Lake concentrate [3.9] showed that at the receiving port (Philadelphia) the concentrate at the surface of the ship's hold had 0.67 to 1.75% moisture while close to the bottom (at a depth of 25' to 38' depending on the ship) had 9.56 to 11.70%; at the bottom free water was observed.

A similar phenomenon is observed during shipments of Mont Wright concentrate. When the shipment arrives at a European port the concentrate in the upper layer of the hold contains about 1% of water by weight while at the bottom there is free water.

To compensate for the trouble caused by handling this suspension, pumping out water, etc. the producer of the concentrate has to give the buyer additional tons of his product involving significant costs. It is obvious too that the buyer pays for dry concentrate only after having subtracted the tonnage of water content, while shipping companies charge for the whole transported mass. The difference further raises the production cost since the cost of transporting one tonne of water to Europe is estimated at $10.00. [The drier the final concentrate the better for the producer].

The concentrate could be effectively dewatered by the use of such technologies as centrifuging, filter-pressing or, especially, thermal drying; however, the costs involved would be prohibitive.

There are two possible ways to overcome difficulties resulting from high moisture content and moisture migration in the Mont Wright final concentrate:

1. Finding another surfactant to be used as a filter-aid which would reduce the residual moisture in the filter cake but would not negatively influence handleability.

2. Finding a water sequestering agent which would prevent moisture migration during transport and storage operations, but would be accepted by buyers as not harmful for subsequent processes.

It is very unlikely that any surfactant filter aid could reduce the moisture level below the limit of its ability to migrate (below about 1%). Therefore to fully prevent the self draining both mentioned ways would have to be used. However, it is quite possible that instead of eliminating, simply reducing migration problems would prove to be satisfactory. In this case finding an adequate filter-aid surfactant would resolve the problem.

Research work done in 1986/87 as reported in this progress report was aimed at finding answers to simple but pertinent and practical questions that would permit development of a detailed program of investigations to reduce the moisture migration in iron ore concentrates.

STATE OF KNOWLEDGE

Abundant technical and scientific literature can be found on dewatering fine grain bulk materials by sedimentation, filtration and centrifuging with and without the use of surfactants. Particular problems connected with dewatering iron ore concentrates are also reflected in many articles and books, e.g., [2,1], [2,2] and others.

For these reasons the program of experiments to be carried out in 1987/88, will include tests aimed at a simple selection of the best surfactant which could improve the effects of filtration without hampering the transportability of the concentrate. A method of measuring the transportability will have to be taken from another field [3.7] and adapted to iron ore concentrate, for this purpose.

However, the broader question of water migration or self drainage of iron ore concentrates and similar materials has apparently not been studied to such an extent and under such circumstances that available results would give examples easily transferable to Mont Wright's particular case.

The flow through porous media and problems of seepage have been studied extensively within soil mechanics and its application to civil engineering and building construction [1.11], [1.12], [1.13].

[7.5]. The main subject of study was however, the mechanics of water flow in a saturated state.

The behaviour of water in bulk materials and in particular in concentrates of iron ore and other ores has been studied extensively for transportation purposes - namely for preventing dangerous shifting of the cargo in ship holds.

F.E. Hanes ([2.6] and other unpublished contributions) from CANMET contributed to works, which were published in several articles, see [3.1], [3.2], [3.3], [3.8], [3.10], [3.11], [3.12], [3.13], [3.14], [3.15], [3.16], [3.17], [3.18]. The most fundamental of works was P.G. Kihlstedt's: Consistency of Concentrates [3.1].

All these works considered moist concentrates in a state close to saturation at about 10 or more per cent moisture. Their main goal was to determine the highest permissible moisture for safe transportation.

Reports on filtration, on the other hand, approached only one part of the question since the goal of this work is studying water migration in concentrates which had already been filtered.

The only field of investigation from which experimental results can, under carefully selected conditions, be transferred to works on moisture migration as it occurs in Mont Wright concentrates, is centrifuging. [4.1], [4.2], [4.3], [6.2], [1.1], [1.2].

To study water migration problems, two approaches can be taken - the mechanical approach and the physico chemical one. The latter would consider e.g., adsorption phenomena and hydration layers on solid particles as well as the use of surfactants and water sequestering agents. An abundance of literature is available in this particular field for example: [1.14], [1.3], [1.10], [6.1], [6.2], [6.3], [6.5].

Part B, EXPERIMENTAL

PHYSICAL/LABORATORY MODEL OF MOISTURE MIGRATION

The random process of moisture migration occurring under the influence of gravity and enhanced by shocks, shaking and probably also vibration can be simulated physically in centrifuges. Capillary water, at a moisture content range of 0.5 to 5%, is contained in the solid skeleton of the concentrate in a so-called pendular state, i.e., mostly in the form of bridges between solid particles. Most of it can be easily drained by centrifuging in a reasonably short period of time (so that effects can be observed under laboratory conditions).

Centrifuges have been used for more than 50 years to model soil behaviour [1.7] and in particular its consolidation and water seepage. General as well as theoretical studies on capillarity and dewatering are supported in most cases by experiments carried out on centrifuges [1.1], [1.2]. Therefore, using centrifuges for physical modelling of water migration in an iron ore concentrate - as proposed in this study - is not novel. The first few experiments described in this report, namely Series 1 to 6, are devoted to further substantiate this choice.

CHARACTERISTICS OF MATERIALS USED IN EXPERIMENTS

CONCENTRATE AND TAILINGS

Handling of the Sample

Experiments were carried out with Mont Wright concentrate and tailings sent for this purpose by M. Tremblay on 10.06.86.

The concentrate came in 4 sealed plastic containers containing about 30 kg each.

The tailings came in 6 similar containers with about 30 kg each.

The concentrate had been tested for moisture content (it contained 4.5%). Tailings arrived fully sealed with free water submerging the surface of the sample.

Both materials were "floor dried" and when they became air dry they were homogenized and stored in closed containers.

All determinations of moisture content were done, according to ASTM Standards.

Assays

A sample of concentrate was sent to the CANMET's Chemical Laboratories for assaying and spectrochemical analyses. These analysis gave the following results

Table 1. Analysis of the Mont Wright concentrate

CANMET analysis			Mont Wright specification (for comparison)
Element	%	Method used	%
Fe	64.99	Chemical analysis	66.3
Fe Sol.	63.48	Chemical analysis	-
SiO_2	5.26	Chemical analysis	5.0
Mn	0.009	quantitative emission spectrometry	0.020
Mg	0.013	quantitative emission spectrometry	0.05 (MgO)
Ti	0.050	quantitative emission spectrometry	0.17 (TiO_2)
Al	0.12	quantitative emission spectrometry	0.34 (Al_2O_3)
Fe	>10	semi quantitative spectrography	
Si	21	semi quantitative spectrography	
Mn	0.052	semi quantitative spectrography	
Mg	0.2	semi quantitative spectrography	
Ti	0.12	semi quantitative spectrography	
Al	2	semi quantitative spectrography	
Pb	0.0012	semi quantitative spectrography	0.006
Zn	0.011	semi quantitative spectrography	0.007
Ag	<0.0001	semi quantitative spectrography	
Mo	0.0006	semi quantitative spectrography	0.005
Cr	0.003	semi quantitative spectrography	0.002
Cu	0.002	semi quantitative spectrography	0.002
Co	0.0009	semi quantitative spectrography	
Ni	0.003	semi quantitative spectrography	0.009
Be	<0.0001	semi quantitative spectrography	
La	0.027	semi quantitative spectrography	
Y	0.048	semi quantitative spectrography	
Sr	0.010	semi quantitative spectrography	
Ba	0.031	semi quantitative spectrography	
Ca	0.2	semi quantitative spectrography	
K	0.9	semi quantitative spectrography	0.008

Particle Size Distribution and Specific Surface

Results of screen tests for both the concentrate and the tailings are shown on the following table and graphs:

Table 2. Screen tests of the concentrate and tailings

Mesh	mm	Concentrate		Tailings	
		% weight on sieve	% cumulative pass.	% weight on sieve	% cumulative pass.
			100.00		
10	1.7	0.8	99.2		
14	1.18	3.1	96.1		
20	0.85	5.1	91.0		
35	0.425	28.4	62.6		
48	0.3	17.8	44.8		100
65	0.212	16.4	28.4	49.1	50.9
100	0.15	13.3	15.1	21.7	29.2
150	0.106	7.3	7.8	12.1	17.1
200	0.075	4.1	3.7	6.7	10.4
270	0.053	1.7	2.0	-	-
325	0.045	0.9	1.1	0.9	9.5
-325		1.1	-	9.5	-

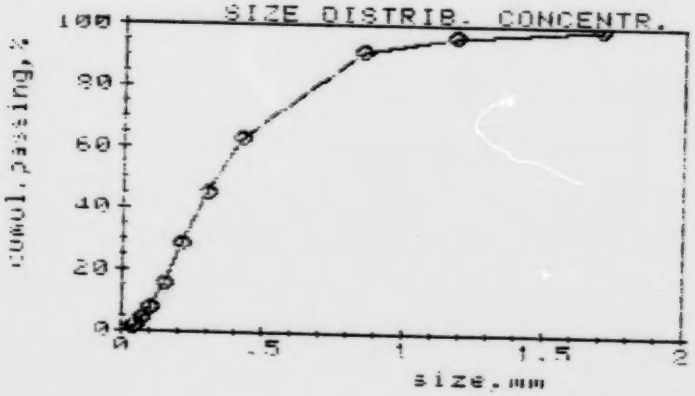

Fig. 1. Size distribution curve of concentrate

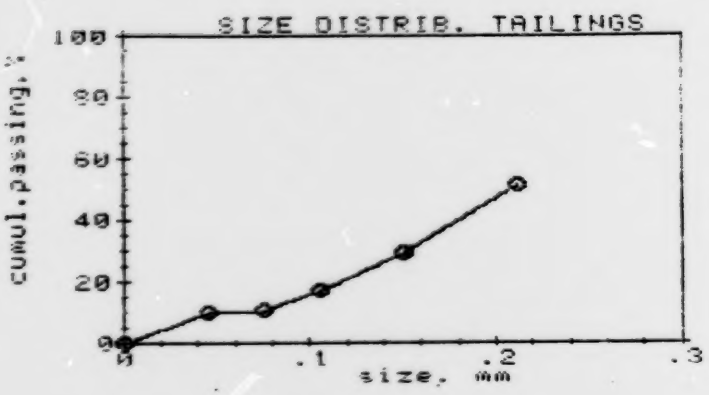

Fig. 2. Size distribution curve of tailings

The specific surface was determined by three methods, namely B.E.T. gas adsorption, Blaine permeametry and calculation of equivalent spheres from the particle size distribution.

The following results were obtained:

<u>Concentrate</u>	
B.E.T.	1000 cm^2/g
Blaine	150 cm^2/g
Calculation	47.7 cm^2/g
<u>Tailings</u>	
B.E.T.	2300 cm^2/g
Blaine	220 cm^2/g
Calculation	-

These results are obviously unsatisfactory. For both B.E.T. and Blaine methods the material was much coarser than in usual CANMET practice, therefore the measuring instruments were not correctly calibrated. The calculation method is seldom accurate unless the shape factor is well determined and the particle distribution in the finest classes is well known. In further studies the question of specific surface will have to be more closely examined.

Specific Weight

The specific weight was measured with the Beckman air comparison pycnometer Model 930 with the following results:

Concentrate: $\delta = 4.90$ g/cm³

Tailings : $\delta = 3.01$ g/cm³

Mineralogy

The mineralogy of Mont Wright iron ore is known from the work of W. Petruk [2.5]. The samples of concentrate and tailings used in this work were examined by J.M.D. Wilson.

The following minerals were identified: hematite, quartz, goethite, biotite and traces of magnetite, rutile and amphibole.

All grains were angular and equidimensional with smooth surfaces, with the exception of goethite, and biotite. Biotite tended to be platy. Goethite was highly irregular with very rough surfaces. There was only one type of quartz identified. No difference in mineralogical composition was observed between the concentrate "as is" and a sieved granulometric class of 0.2 - 0.7 mm. Goethite is not equally distributed as seen in the following table.

Table 3. Distribution of goethite in the concentrate

Mesh	mm	Size fraction in the sample %	% goethite in the fraction	% goethite in the sample
+28	+0.6	20.4	0.23	0.07
+35-28	+0.5-0.6	8.0	1.49	0.12
+48-35	+0.3-0.5	17.8	0.44	0.08
+65-48	+0.212-0.3	16.4	2.47	0.41
+100-65	+0.150-0.212	13.3	0.68	0.09
+150-100	+0.106-0.15	7.3	1.1	0.08
+200-150	+0.075-0.106	4.1	0.45	0.02
0-200	-0.106	3.7	0.78	0.05
				0.92

It is known from other studies that water retention characteristics of goethite was significantly different from other minerals present, however, it is very unlikely that this small content of goethite in concentrate (0.92% by weight) could significantly influence its water retention properties.

Auxiliary Materials Used for Experiments

Peat Moss

High-moor fibrous peat moss sent by D. Miller, Port Cartier, was used as water sequestering agent. The original moisture content of this material was about 92%. When dried below 60% moisture it can be easily ground in a hammer mill or in a fast turning stirring device. Other characteristics of this peat moss are given in results of specific experiments.

Bentonite

Finely ground Wyoming bentonite with a moisture content of 10% was used as water sequestering agent.

Lignosol

Calcium lignosulphonate (Lignosol BD/B) supplied by Reed Lignin, Québec was used as a disperging agent. According to specifications it contained:

moisture - 7%
total S - 6.1%
Ca - 4%

and had a pH of about 4.

Flocculant Superfloc A100 (Cyanamid)

This anionic flocculant proved to be the best for thickening Mont Wright iron ore pulp as established experimentally by J. Leung, CANMET [2.10].

DESCRIPTION OF BASIC EQUIPMENT

For centrifuging experiments a laboratory centrifuge with changeable speed was used. Its main characteristics are as follows:

Manufacturer	:	Central Scientific Co. Chicago, Model CL
Maximum speed	:	2100 rpm
Maximum central acceleration	:	108 g (g - acceleration of gravity)
Dimensions of tubes	:	D = 20 mm; h = 95 mm
Volume	:	v = 28 mL

For further experiments CANMET's technical services constructed a larger centrifuge using parts of an old centrifuge which had been out of order for many years. Its characterisics are as follows:

Maximum speed	:	1750 rmp
Maximum central acceleration	:	161 g
Dimensions of tubes	:	D = 28 mm; h = 185 mm
Volume	:	85 mL

EXPERIMENTS: RESULTS; TABLES AND GRAPHS

SECTION 1. TESTING CENTRIFUGING AS A PHYSICAL MODEL OF WATER MIGRATION

Series* 1. Centrifuging Mount Wright concentrate with initial moisture W = 11.27% (by weight)

Table 4.

Speed ~2100 rpm

Spinning time minutes	% moisture		Remarks
	Upper part of the test tube (residual)	Lower part of the test tube	
1	9.84	12.30	
2	8.80	12.68	
5	10.45	12.18	From Series 2
10	10.06	12.48	
10	9.37	11.23	

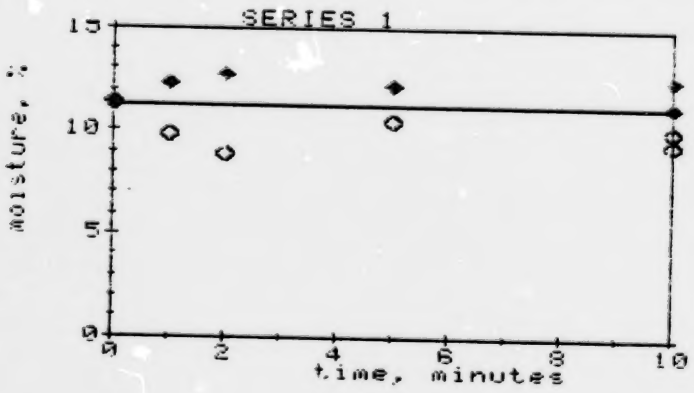

Fig. 3. Results of centrifuging; Series 1

Conclusion:
1. There is a separation (in spite of the fact that 11.27% moisture is close to saturated state (~13 to 14%)
2. After 1 to 2 minutes the process of draining ends.
3. Results are reproducible.

* For clearness single tests were grouped into series.

Series 2. Centrifuging concentrate at initial moisture W = 11.38%. Reproducibility of results

Table 5.

Speed 2100 rpm
Time 5 minutes

Statistical parameters	Upper part (residual)	Lower part
	10.71	11.97
	10.48	12.18
	9.80	12.45
	10.82	12.13
Variance	0.16	0.03
Standard Deviation σ	0.40	0.17
$\bar{x}$	10.45	12.18

Conclusion: Results are reproducible.

Series 3. Reproducibility of results. Centrifuging tailings at initial moisture W = 17.43%

Table 6.

Speed 2100 rpm
Time 5 minutes

Statistical parameters	Moisture content %	
	Upper part (residual)	Lower part
	17.36	18.15
	15.65	18.81
	15.22	18.89
	15.41	18.76
Variance	15.91	18.65
Standard deviation σ	0.85	0.29
$\bar{x}$	0.72	0.09

Series 4. Time of moisture equalizing in the test tube.

(Checking time after which the self equalizing of moisture in the tube may influence results of centrifuging)

Table 7.

Initial moisture W = 9.82%
Speed 1750 rpm

Time of emptying the upper part of tube	moisture %		
	Upper part (residual)	Lower part	Difference
1. immediately (after spinning)	4.41	12.06	7.65
2. immediately	3.96	12.37	8.41
3. after 2 minutes	4.59	11.93	7.34
4. after 10 minutes	6.32	11.29	4.97

Conclusion: After 10 minutes the difference starts to be meaningful

Series 5. Centrifuging concentrate with lower moisture content, for longer time

Table 8.

Initial moisture Wx = 4.5%
Speed 2100 rpm

Spinning time (hours)	moisture %		
	Upper part (residual)	Lower part	Difference
1	0.80	10.56	9.76
2	0.93	10.36	11.29
2	0.83	11.14	10.31
2 plus 1 minute vibrations	1.41	7.36	5.95

Conclusions:
1. Draining occurs with relatively low moisture content (Wx = 4.5%)
2. Results are reproducible.
3. There is no difference between 1 h and 2 h spinning
4. The residual moisture content is below 1%
5. During vibrations some equalizing of moisture occurs (one result only)

Series 6. Repeating test as in 'Series' 5 but with another material (tailings)

Table 9. Initial moisture W = 4.5%
Speed 2100 rpm

Spinning time (hours)	moisture %		Difference
	Upper part (residual)	Lower part	
1	1.75	9.95	8.2
2	1.27	9.19	9.38
2	1.33	8.30	6.97
1 plus 1 minute vibrations	1.39	10.21	8.82

Conclusions:
1. Draining occurs with initial moisture content W = 4.5.
2. Results are reproducible.
3. The residual moisture content is between 1. and 2%; higher than in case of concentrate.
4. During vibration no equalizing moisture observed.

Series 7. Centrifuging concentrate with low initial moisture (W = 1.00%)

Table 10. Speed 1450 rpm

Spinning time (spinning)	Upper part (residual)		Lower part
		Average	
5	1.19	1.16	1.17
5	1.13		1.17
15	1.15	1.12	1.22
15	1.08		1.06
30	0.98	0.91	0.96
30	0.83		0.97
40	1.01	1.00	1.18
40	0.98		1.03

Conclusions:
1. At the initial moisture W = 1% no water draining has been observed.
2. Results are reproducible.

SECTION 2. KINETICS OF WATER DRAINAGE

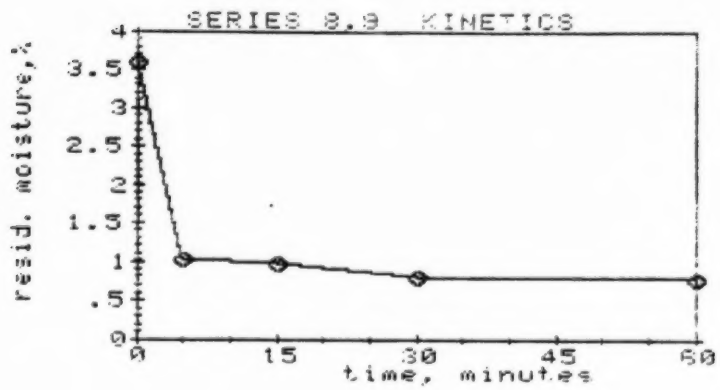

Fig. 4. Kinetics of water drainage by centrifuging; Series 8, 9

Series 8, 9. Kinetics of water drainage. Centrifuging concentrate with the initial moisture W = 3-3.6%

Table 11.

Speed 1750 rpm

Spinning time minutes	moisture %		
	Upper part (residual)	Lower part	Difference
5	0.98	3.74	2.76
	1.01		
5	1.04	3.63	2.59
15	0.93	3.69	2.76
	0.97		
15	1.00	3.66	2.66
30	0.76	5.09	4.33
	0.80		
30	0.84	5.23	4.39
60	0.71	5.08	4.37
	0.76		
60	0.80	4.53	3.73

Conclusions:
1. After 30 minutes of spinning the draining is completed .
2. Results are reproducible and coherent with results obtained formerly in other series.
3. The residual moisture level corresponds with moisture observed in upper layers of the holds of ships [3.9].

Series 10. Kinetics of water drainage. Centrifuging tailings with initial moisture W = 3.5%

Table 12.

Speed 1750 rpm

Spinning time (minutes)	moisture %		
	Upper part (residual)	average	Lower part
5	2.69	2.78	3.86
5	2.87		3.73
15	2.47	2.36	3.90
15	2.24		4.05
30	2.26	2.27	4.27
30	2.28		3.92

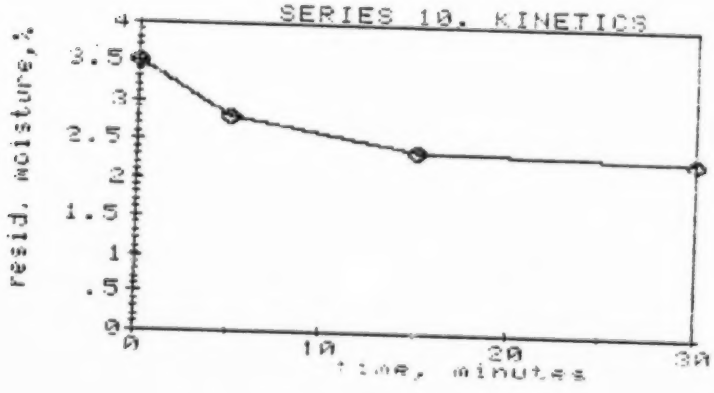

Fig. 5. Kinetics of water drainage by centrifuging; Series 10.

Conclusions:
1. After 30 minutes of spinning the draining is complete.
2. Results are reproducible and coherent with results obtained formerly in other series.
3. The residual moisture of tailings is higher than of concentrate.

SECTION 3. IMPACT OF ADDITIVES ON WATER DRAINAGE

Series 11, 12. Sequestering water in concentrate with Wyoming bentonite

initial moisture ~ 3.7%
moisture in bentonite ~ 10 %
time of spinning 30 minutes

Table 13.

% of bentonite (wet weight)	moisture %			Difference
	Upper part (residual)	average	Lower part	
0.1	1.72	1.71	3.69	1.97
0.1	1.7		4.17	2.47
0.2	2.39	2.33	3.7	1.31
0.2	2.27		3.61	1.34
0.3	2.94	2.94	3.25	0.31
0.3	2.94		3.28	0.34
0.4	3.10	3.23	3.11	0.01
0.4	3.36		-	-
0.5	3.47	3.41	3.67	0.2
0.5	3.35		3.57	0.22
1	3.71	3.74	3.81	0.7
1	3.77		3.79	0.02
1.5	3.67	3.66	3.73	0.06
1.5	3.65		3.73	0.08
2	3.7	3.7	4.15	-
2	-		-	-

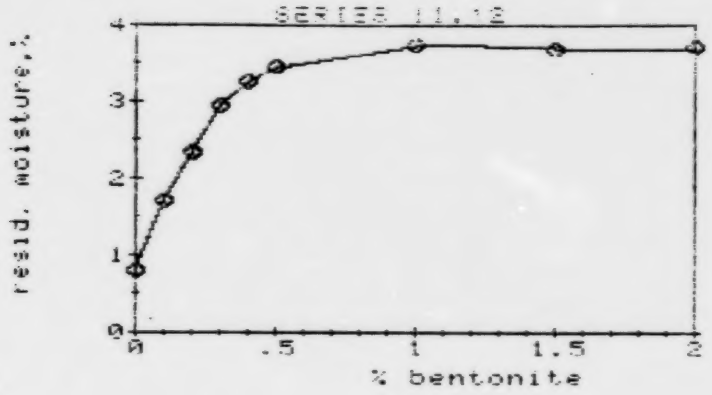

Fig. 6. Sequestering water with bentonite; Series 11, 12.

Conclusions:
1. Addition of bentonite sequesters water i.e. prevents draining
2. After adding 0.5% bentonite draining stops

Series 13, 14. Testing influence of lignosol on draining of concentrate

initial moisture ~3.5%
speed 1750 rpm
time 30 minutes

Table 14.

% of lignosol (wet weight)	% moisture		
	Upper part (residual)	Average	Lower part
0.005	0.95	0.94	5.64
0.005	0.93		5.04
0.01	0.84	0.86	5.56
0.01	0.88		5.69
0.02	0.67	0.74	5.19
0.02	0.8		6.56
0.03	0.71	0.74	5.93
0.03	0.77		6.78
0.05	0.62	0.59	4.31
0.05	0.56		4.04
0.1	0.5	0.57	4.37
0.1	0.64		4.17
0.2	0.32	0.38	3.66
0.2	0.43		3.62
0.5	0.45	0.38	-
0.5	0.31		-

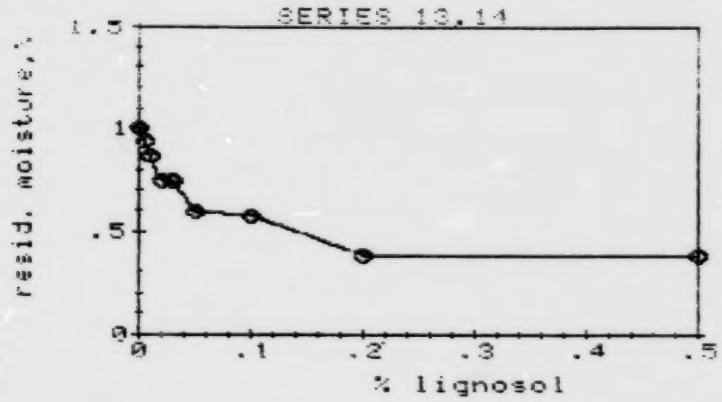

Fig. 7. Impact of lignosol; Series 13, 14

Conclusions:

1. Addition of lignosol diminishes the residual moisture content
2. The lowest residual moisture that can be achieved with the help of lignosol is about 0.4%
3. The concentrate dewatered by centrifuging with the help of lignosol changes its flow parameters. Particular grains tend to stick together. Becomes hard when dried, not flowing

Series 15. Microscopic Characteristics of peat moss used, dried at room temperature.

Table 15.

Drying time hours	Moisture, %	Appearance
0	92.2	Almost free water, dark
5	90.0	Completely soaked, dark
11	89.02	Paste , dark
14	86.5	Paste when pressed, dark
24	48.45	Sticky when pressed, slightly lighter

Conclusion: Peat moss dries slowly enough, can be handled at room temperature without influencing results of tests.

Series 16. Behaviour of peat moss in the centrifuge (peat moss only)

Table 16. Spinning time 30'
Speed 1750

Initial moisture %	final moisture	
	Upper part (residual)	Lower part
67	67.37	66.92
80	79.62	80.97
80	80.92	81.50
89	88.63	89.04
89	88.72	89.14
91	90.61	91.71

Conclusion: 1. Water in peat moss with initial moisture content in the range of 67 to 91% does not drain down during centrifuging.

Series 17. Influence of peat moss addition on draining concentrate.

initial moisture of concentrate W = 3.5%
initial moisture of peat moss Wp = 86.5%
spinning time t = 30'
speed 1750 rmp

Table 17.

% of peat m. added wet basis	Initial moisture before spinning %		Upper part (residual		Lower part
	Calculated	Measured		Average	
1	4.3	4.61	1.88	1.91	6.17
1	4.3	3.91	1.93		4.76
2	5.13	4.89	2.19	2.22	6.19
2	5.13	4.39	2.24		5.62

Conclusions: 1. Addition of peat moss with high water content probably slows down drainage but not sufficiently. Inconclusive results.

Series 18. Influence of peat moss addition on draining concentrate - Repeating Series 17

initial mixture of concentrate W = 3.5%
initial moisture of peat moss Wp = 86.5%
spinning time t = 301 units
speed 1750 rpm

Table 18.

% of peat m. added wet basis	initial moisture before spinning a%	% moisture after spinning		Difference a-b
		Upper part (residual), b%	Lower part	
1	4.29	2.07	5.33	2.22
1	4.26	1.94	5.28	2.32
2	5.34	2.30	6.98	3.04
2	4.56	2.45	2.45	2.11
5	6.74	5.23	7.47	1.51
5	-	6.06	-	-
7	9.04	7.25	9.67	1.79
7	9.17	6.72	9.17	2.45

Conclusions:
1. Addition of peat moss with high water content slows down drainage but not sufficiently.
2. Possibly to stop drainage, peat with much less moisture will have to be used.

Series 19. Influence of peat moss addition on draining concentrate

initial mixture of concentrate W = 3.5%
initial moisture of peat moss Wp = 47%
spinning time t = 30'
speed 1750 rpm

Table 19.

No.	% of peat added (wet weight)	initial moisture before spinning		% moisture after spinning			Difference a-b
			Average, a	Upper part	Average, b	Lower part	
1	1	3.79	3.86	2.96	3.11	4.24	0.75
2	1	3.92		3.26		4.19	
3	3	5.00	4.88	4.92	5.08	5.03	
4	3	4.75		5.23		4.58	- 0
5	3	4.11	-	4.24		4.04	- 0
6	3	2.95		this result not valid			

Conclusion:
1. This series does not give very coherent and therefore reliable results, probably because of presence of relatively large pieces of peat moss which could not be well mixed with the concentrate. It needs to be repeated using ground peat.
2. Addition of 1% of peat moss does not prevent draining, but decreases it.
3. Addition of 3% peat moss (wet weight prevents draining).

Series 20. Influence of peat moss addition on draining moisture from the Concentrate

(In tests 1-8 peat moss was ground to ~1 mm approximately)

Initial moisture of conc. W = 3.5%
Initial moisture of peat Wp = 33%
spinning time t = 30 min
speed 1750 rpm

Table 20.

No.	% peat added		Initial moisture (before) spinning %		moisture, % after spinning			Difference a-b	Remark
					Upper part (residual)		Lower part		
	wet weight	dry weight	measured	a average		b average			
1	0.5	0.34	3.62	3.54	2.09	2.05	4.59	1.49	
2	0.5	0.34	3.46		2.00		4.23		
3	1	0.67	3.71	3.71	2.92	2.82	4.03	0.89	
4	1	0.67	3.71		2.68		4.23		
5	2	1.34	4.14	4.09	3.75	3.74	4.29	0.35	
6	2	1.34	4.04		3.72		4.14		
7	2.5	1.68	3.74	3.84	3.63	3.74	3.79	0.10	In this case the sample might have slightly dried up
8	2.5	1.68	3.97		3.84		4.05		
9	3	2.01		4.88		5.08	-	- 0	Taken from series 19
10	3	2.01		4.11		4.24	-	- 0	

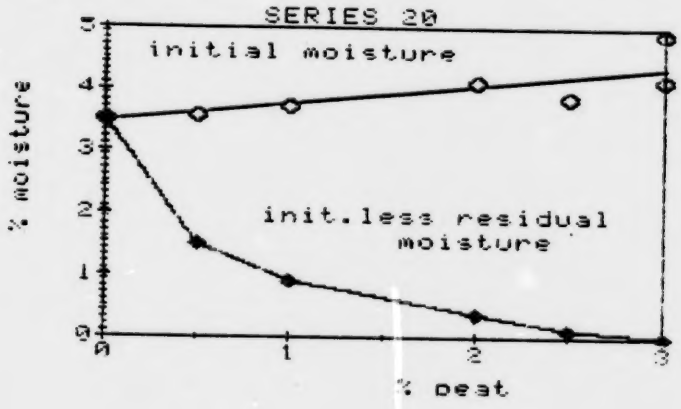

Fig. 8. Sequestering water with peat moss; Series 20

Conclusions: 1. At about 2.5-3% (wet weight) peat moss added (this is equivalent to 1.7-2% dry weight) moisture draining stops.

2. Adequate preparation of peat moss before test would probably significantly diminish its quantity necessary for preventing water draining in the concentrate.

It is very likely that such preparation could decrease the necessary quantity of peat moss by half.

In this test peat moss has been dried below the moisture limit (40-50%) at which it becomes hydrophobic. In practice it would be better to use peat with over 50% of moisture or to use surfactants to make peat hydrophylic again. Also the use of alkali reagents like NaOH for pH control usually improves the water sequestering properties of peat. Finer grinding of peat would improve the homogeneity of its mixture with concentrate and further raise its sequestering properties.

Series 21. Influence of flocculant Superfloc A100 on draining of concentrate.

Table 21.

initial moisture W = 3.5%
speed 1750 rpm
spinning time 30 min.

grams of agent added per 1 tonne of conc.	% moisture	
	Upper part	Lower part
	average	
0.0018	0.80	4.08
0.0018	0.70	4.34
0.0036	0.75	4.38
0.0036	0.76	4.65
0.0072	0.64	4.28
0.0072	0.69	4.38
0.0104	0.73	4.61
0.0104	0.74	4.51

Conclusion:
1. No influence observed when the agent was added at this quantity.
2. It is very likely that for this purpose much more surfactant should be used.

(This rate was the best for thickening)

EXPERIMENTS: DISCUSSION OF RESULTS

SECTION 1. TESTING CENTRIFUGING AS A PHYSICAL MODEL OF WATER MIGRATION

As mentioned before, Series 1 to 7 (see pages 13-16) of experiments served to substantiate the choice of a centrifuge as a tool for investigating water migration in concentrate.

Experiments show that results of centrifuging the concentrate within the chosen range of moisture are reproducible. Once the moisture has drained down in the test-tubes spun in the laboratory centrifuge, it forms a layer of fully saturated concentrate at the bottom. This water, if left alone, slowly rises in the tube because of capillary pressure. Test series 4 showed that this occurs slowly enough that it does not affect the results of experiments.

SECTION 2. KINETICS OF WATER DRAINAGE

Series 8, 9 and 10 (see pages 17-18) show that the rate of water drainage follows a curve which could be represented with sufficient accuracy by an exponential equation of the type

$$y = ae^{bx+c}.$$

which is a common kinetic equation for for this type of process. This curve would have an asymptote: $y = c$. For this experiment c is equal to the residual moisture after spinning. This shows that longer spin times than 30 minutes without substantially changing other conditions e.g., the speed, temperature or characteristics of material (like surface tension size distribution) would not influence the value of the residual moisture. For concentrate this residual moisture value is about 0.8% while for tailings it is about 2.3%. These results were confirmed by experiments in series 5 and 7 and to a degree in series 6.

Series 7 (see page 18) also shows that when material is centrifuged with initial moisture close to the value of c, (0.8 to 1% for concentrate), practically no drainage occurs.

It probably could be assumed that if at Mont Wright the concentrate was dewatered up to this limit; no moisture migration would occur during transportation and storage.

Series 1 to 10 (see pages 16-20) seem to sufficiently substantiate the choice of centrifuging as a physical model of water migration during transport and storage of the concentrate. The amount of residual moisture in the concentrate (0.8 to 1.2%) is close enough to the moisture content observed in the upper layers of holds of ships, railway cars and bins [3.9], [2.7].

SECTION 3. IMPACT OF ADDITIVES ON WATER DRAINAGE

Series 11 and 12 (see pages 19-20) show that it is possible to prevent self draining of concentrate by adding 0.5 to 1% (wet weight) of bentonite. It is very likely that supplementary use of small amounts of some chemical agents, like water soluble organic polymers, could reduce the amount of bentonite needed [7.3]. Concentrate with bentonite, within the percentage and moisture range of these experiments, does not show any change of characteristics that might influence its transportability. However, this would have to be confirmed by additional measurements.

The addition of 0.5% bentonite raises the SiO_2 content in the concentrate by about 0.3% and the Al_2O_3 by about 0.1% [7.6], which would practically not influence the concentrate specification.

Series 13 and 14 (see pages 21-22) were carried out to check what influence would the addition of a cheap agent - lignosol have, which is known for its stabilizing and disperging properties. The use 0.5% of lignosol reduces the residual moisture in the concentrate by at least a factor of 2, however, the dewatered concentrate may create problems during handling, since it becomes sticky.

Series 15 and 16 (see page 23) were carried out to check the water retaining characteristics of peat moss and its behaviour in a centrifuge. Peat moss has been chosen for further experiments because:

1. it is known for its excellent moisture retention properties;
2. its presence in the saleable concentrate should be easily accepted by buyers because it could improve the energy balance of the sintering process.

About 90 to 98% of dry peat moss consists of organic material. The remaining 2 to 10% after burning forms ash. The ash contains mainly Fe oxides the other components being Ca, Al_2O_3 and in much smaller amounts other elements/compounds.

Series 17 to 20 (see pages 24-28) was carried out to test influence of adding peat moss as water sequestering agent.

The results show that peat moss added in a quantity of 1.7 to 2% dry weight prevents moisture draining. Concentrate with peat moss at this percentage and within this range of moisture does not seem to change its transportability or "flow properties". This, however, would have to be proven by special measurements. It is very likely that the amount of peat moss to be possibly used for stopping moisture draining could be effectively reduced by adequate preparation of peat moss. Better grinding, use of peat moss not dewatered below its hydrophylicity limit (about 40 to 50%) and/or the use of adequate surfactants like sodium dodecyl sulphate and/or controlling pH by using for example NaOH could probably lead to decreasing substantially the amount to be used.

Series 21 (see page 29) was carried out to start investigating the influence of surfactants on self draining of concentrates. Superfloc A100, a product of Cyanamide has been chosen to be tested first because it proved to be highly efficient as a sedimentation aid for the iron ore pulp of Mont Wright.

Results obtained up-to-date are inconclusive. Broader range of quantities of this agent per unit of concentrate has to be checked in order to get any meaningful results.

Several other anionic and cationic flocculants will have to be tested in order to check their possible influence on water drainage and on results of filtering of the concentrate.

Results of lignosol addition (see series 13 and 14) as well as industrial results of using Alchem 8103 and other surfactants as filter aids [2.7], [2.8], show that surfactants are capable of changing the water retaining characteristics of the iron ore concentrate.

SHORT TERM PROGRAM FOR FURTHER EXPERIMENTAL WORK

1. Further studying moisture drainage

   a. Kinetics of dewatering to be studied on Mont Wright and other concentrates as well as on tailings
      - using small centrifuge, (S.C.)
      - using large centrifuge, (L.C.)
   b. Kinetics of dewatering to be studied on ground concentrate
      - slightly ground to refresh the surface
      - ground to change the size distribution
   c. Kinetics of dewatering of selected size fraction
   d. Kinetics of draining on vibrating table
   e. Kinetics of draining on the cement flow test table

2. Completing work on water sequestering

   a. Establishing the best conditioning procedure for peat moss.
   b. Investigating sequestering of water using S.C. and L.C.
   c. Repeating tests with bentonite, S.C.

3. Investigating filtration and the use of filtration aids

   a. Testing twelve different surfactants as filter aids without and with steam

4. Measuring the transportability of iron ore concentrate

   a. Adaptation of the plastograph used for ceramics to measuring the transportability of iron ore concentrate
   b. Adaptation of the S index used for wet fine coals to measuring the transportability of iron ore concentrate

The above proposed program should:

- confirm preliminary results of investigations carried out in 1986/87.

- help to definitively decide whether or not water sequestering action to prevent self draining has an industrial potential.
- explore the technical potential for diminishing costs (incurred by Mont Wright concentrator) of the use of steam in summer time as a filtration aid and costs resulting from water migration.